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Institute for Maintenance Science and Technology

ATMOSPHERIC PLASMA FOR SURFACE MODIFICATION

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NC STATE UNIVERSITY



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Engineering for Aerospace and Defense**
February 8-10, 2011
New Orleans, Louisiana

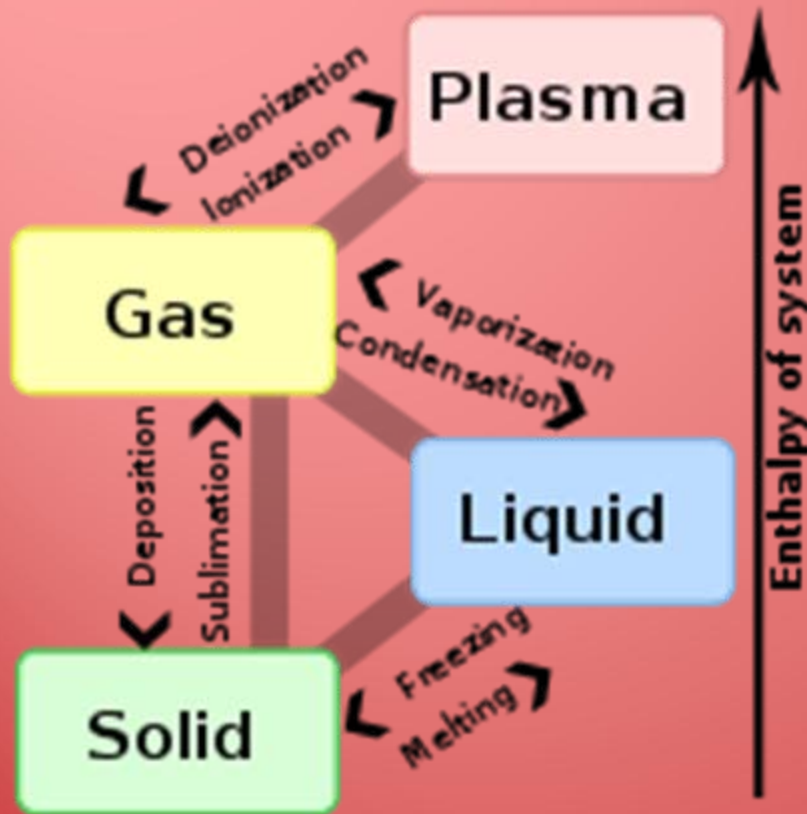


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Brief

- Atmospheric Plasma Explained
- Applications of Cold Plasma
- Commercial Devices
- Examples

4th State of Matter



>95% of matter in the universe is Plasma

Plasma generated by

- Heat
- Voltage
- EMR
- Laser
- Nuclear reactions

Atmospheric Plasma processing occurs at atmospheric pressure

www.wikipedia.com

Parallel Plate

Paschen's Law (1889) governs the breakdown of gas between plates

$$V = \frac{a(pd)}{\ln(pd) + b}$$

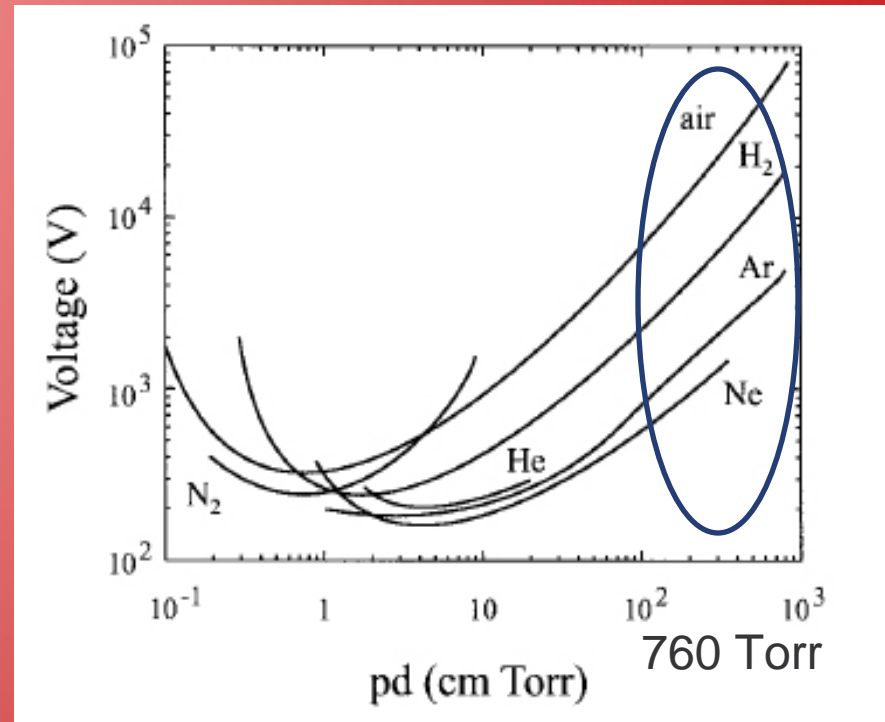
V = breakdown voltage

p = pressure

d = distance between electrodes

a and b are constants dependent on gas

$$pd = e^{1-b}$$



Paschen curves for common gases

Schultz, IEEE Trans. Plasma Sci (26)6 1998

Plasma Classification

- Equilibrium vs. Non-Equilibrium

LTE = Local Thermodynamic Equilibrium

$$T_e = T_g$$

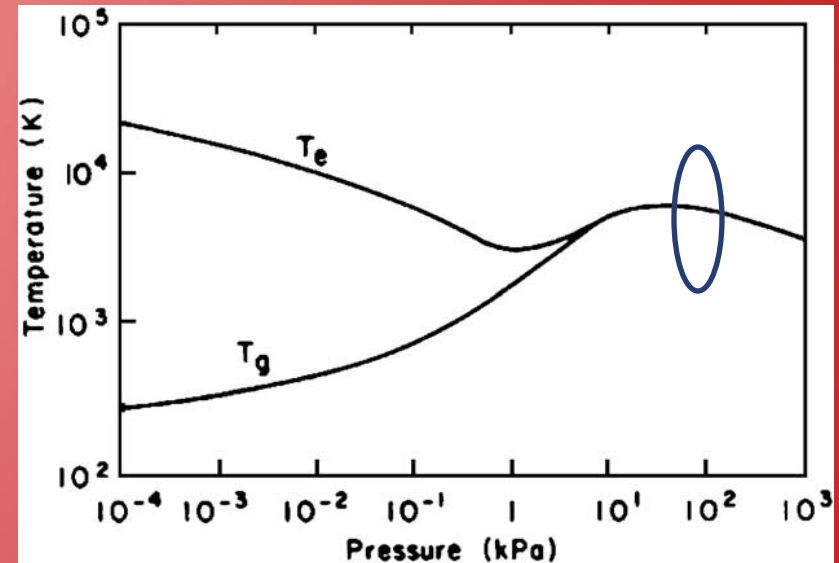
T_e = electron temperature

T_g = gas temperature

- Thermal vs. Cold Plasma

(arc transition)

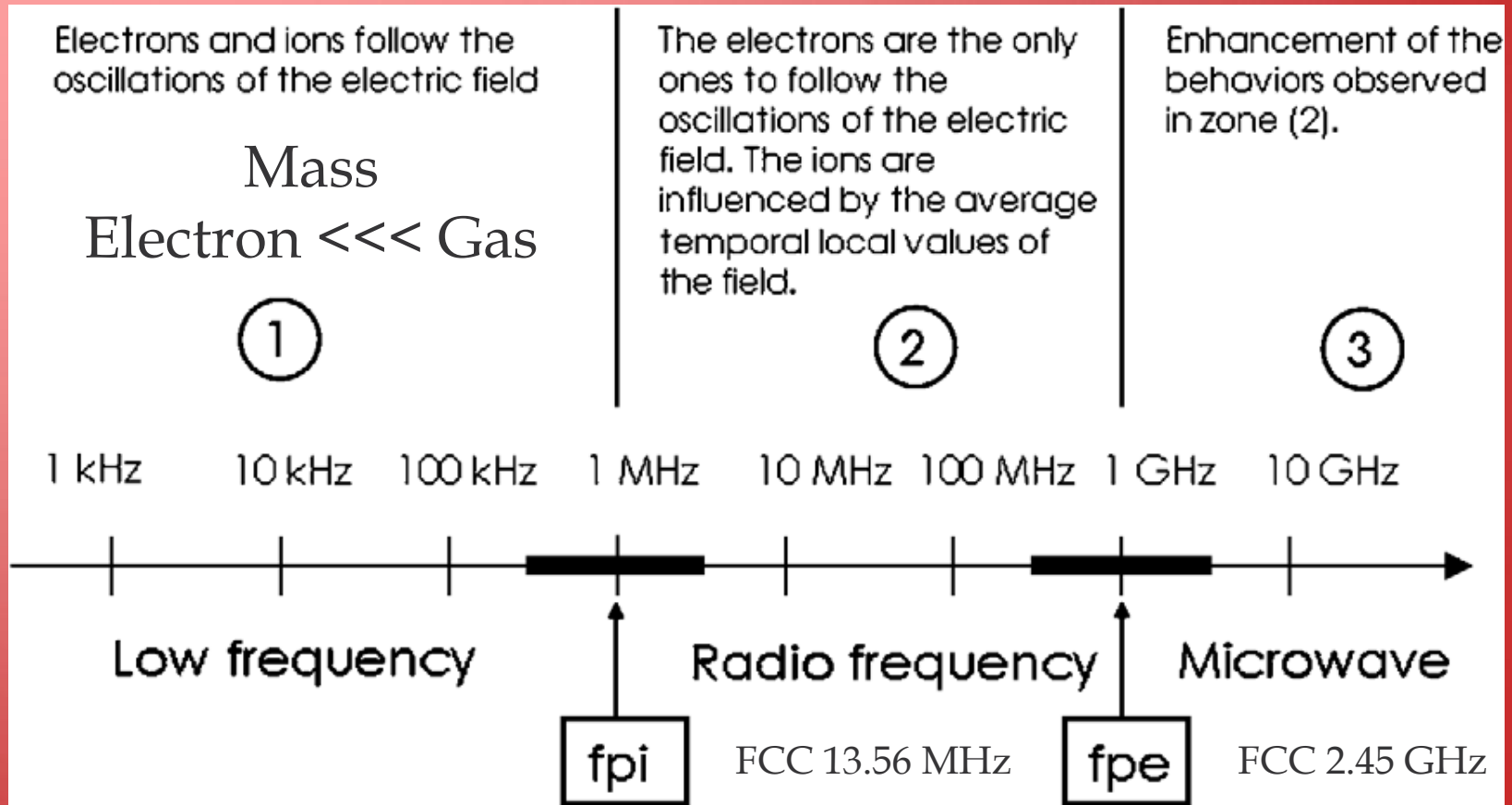
Ion/neutral temperature
and degree of ionization



Tendero Spectrochim Acta B 2006

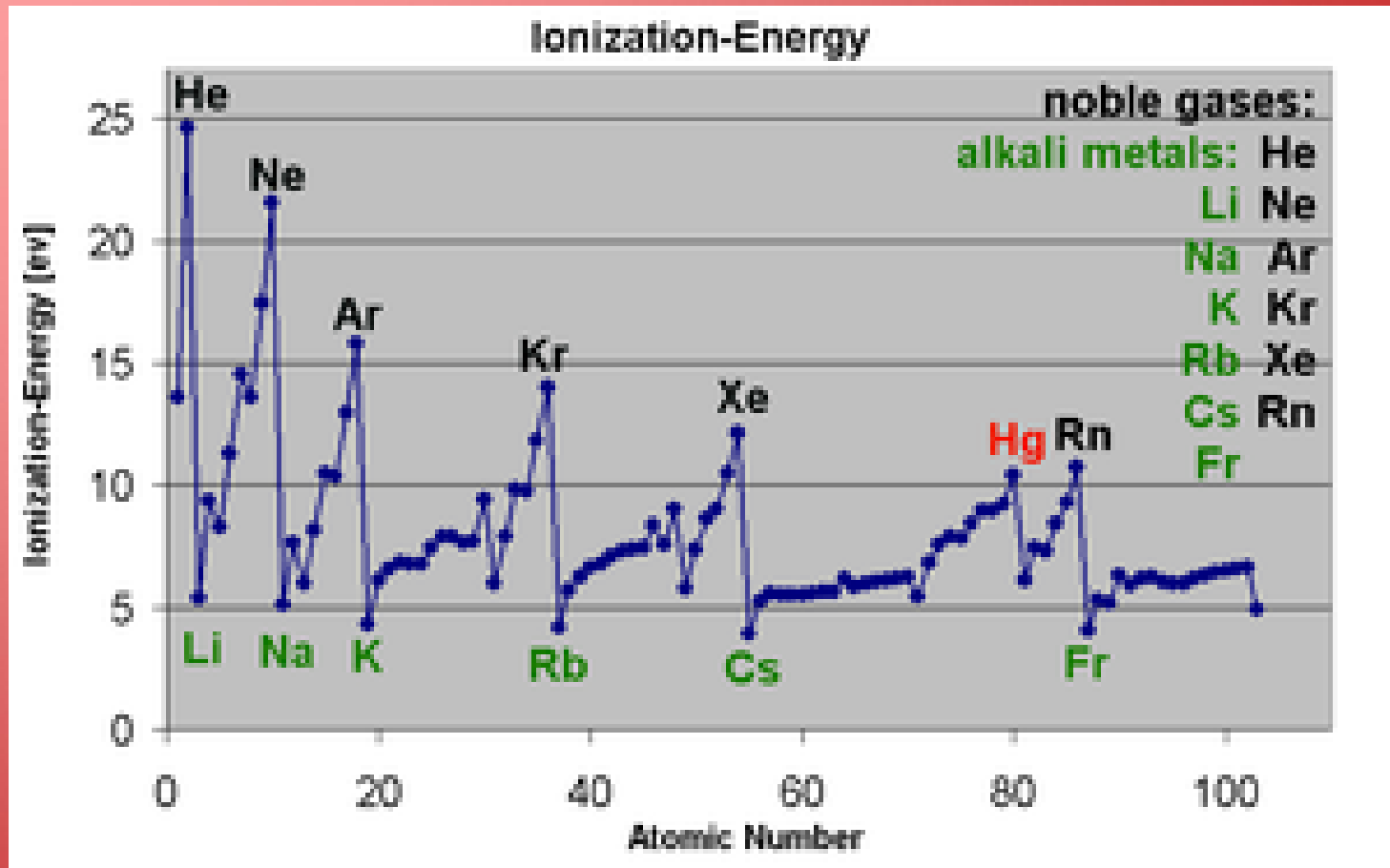
1 atm	101.325 kPa (N/m ²)	1.01325 Bar	760mm Hg	760 Torr	14.696 psi
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Frequency Effects



Tendero Spectrochim Acta B 2006

Ionization Energy vs. Atomic Number



Wikipedia.org

Plasma Composition

- Neutrals

He, Ar, O₂, N₂, H₂, CO₂

- Free electrons

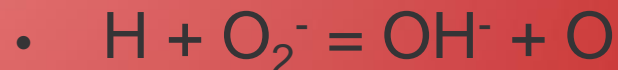
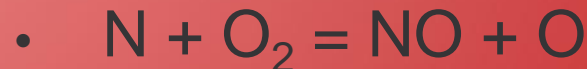
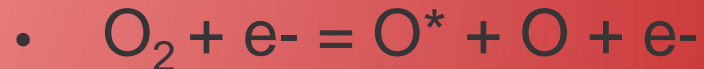
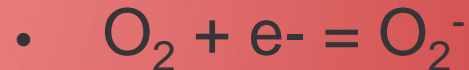
- Positive and negative ions

- Stable and meta-stable active species

- Monatomic and polyatomic species

- Radicals

Examples



Free electron density vs. electron Temperature

Applications

- Cleaning down to the atomic level
Finger oils, silicone oils, hydraulic fluid, sizing, solder flux, carbon soot, machining fluids, mold release agents
- Treatment
Cross linked barrier coatings, dry low friction surfaces
- Deposition
Polymerized hydrocarbon coatings, chemical barriers, scratch resistant coatings, glass-like surfaces, diamond like films

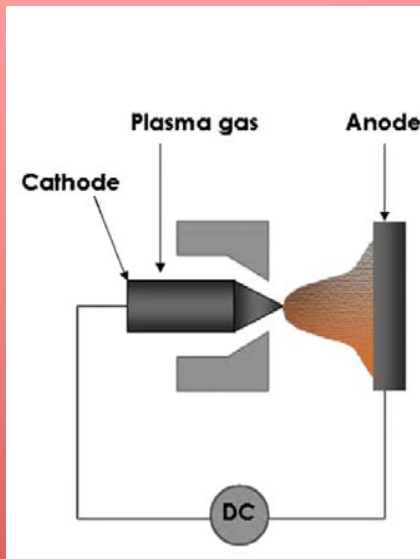
Applications

- Oxidation/reduction
Organic and inorganic functionalities
- Activation.
Hydroxyl, carboxylic, carbonyl, amine, vinyl, thio functionalities
- Adhesion enhancement
Grafting of functional groups, hydrophobic or hydrophilic surface

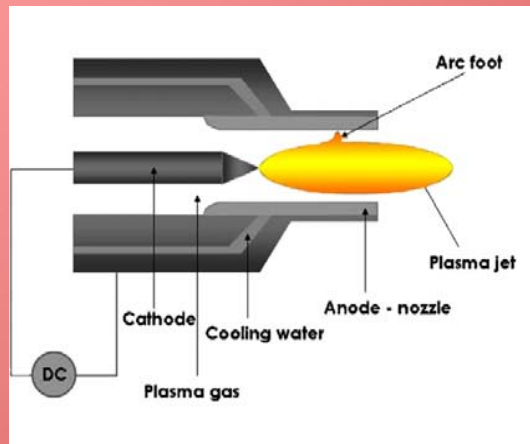
Biomedical Applications

- Sterilization of medical devices and implants
- Air decontamination and biocides
- Antiseptic, fungicide, disinfection
- Bio-functional sites for subsequent attachment of cells, proteins, drugs, bio-conjugated polymers
- Food and food processing disinfection
- Textile chemistry

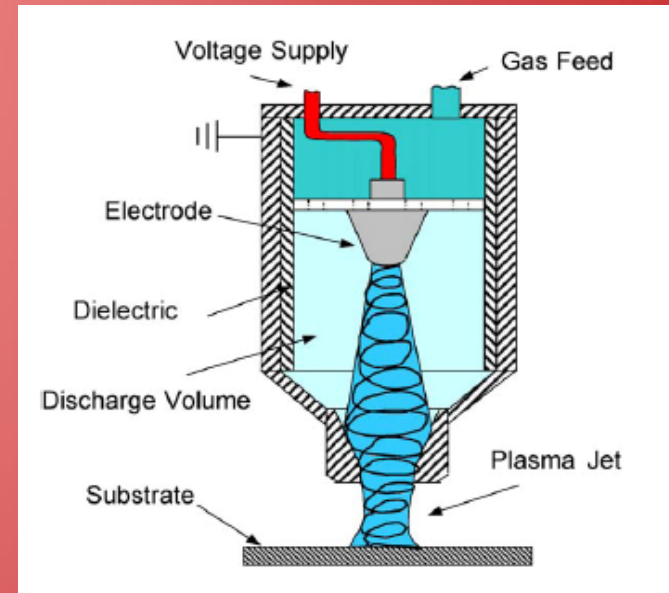
“Torch” Schematics



Transferred Arc



Pilot Arc



Schematic of **Hot DC** plasma devices

Tendero Spectrochim Acta B 2006

Schematic of a **Cold AC** plasma device

C. Noeske, Int.J.Adh.Ad. (24) 2004

Atmospheric Plasma “Torches”



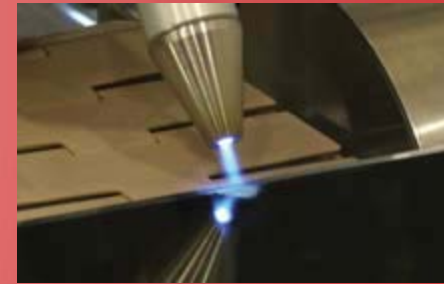
Diener
Plasma beam



PVA Tepla
Plasma Pen



AcXys
ULS



Enercon
Dynamite IT



AP Solutions
Plasma Flux



Apjet
Round Jet

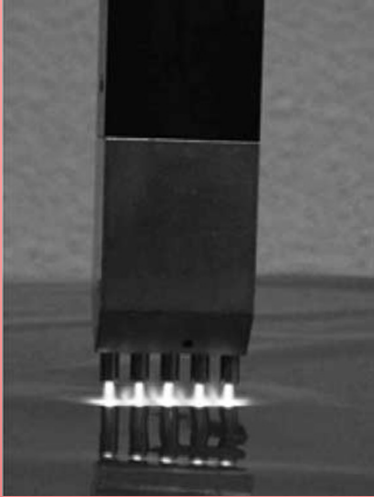


Plasmatreat
FixedJet

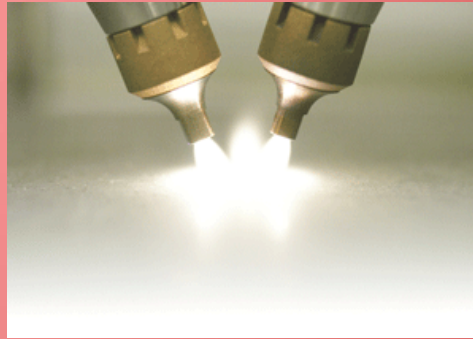


Plasma dyne

Multiple Nozzles



PVA Tepla
Plasmapen



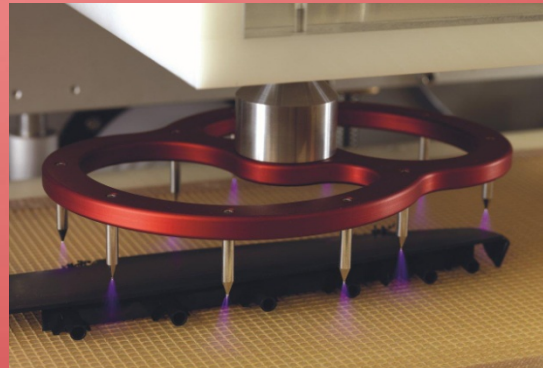
Diener
Dual Beam



AcXys
ULS



Tantec
MonTEC



Tantec
corona

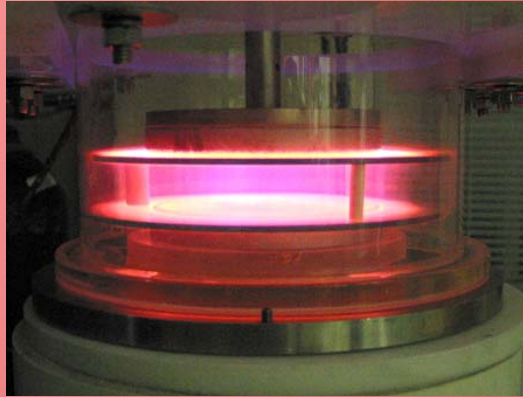


www.bmfd.de

Parallel Plate



AP Solutions



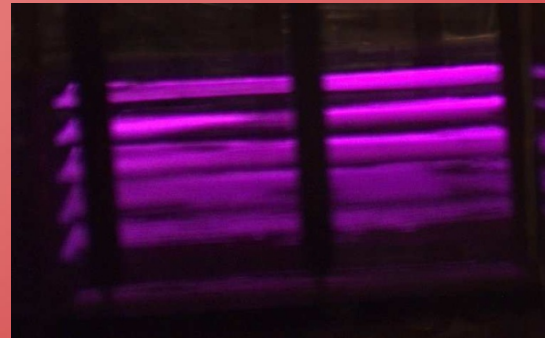
NCSU DBD



Fraunhofer



Enercon Plasma VCP



One Atmosphere Uniform Glow
IEEE Trans. Plasma Sci. 2007

Linear Arrays



Enercon
Plasma3 VCP



Tantec
SpotTEC



Enercon
DynaAMite



Apjet
Flatjet

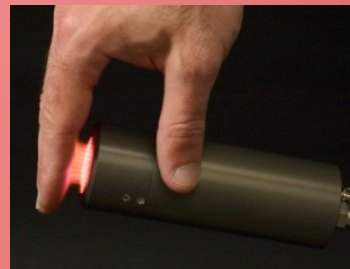


Apjet
Texjet

Alternate Geometries



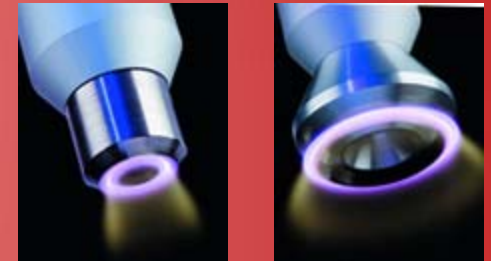
Apjet
Round Jet



Surfx
Atomflo



Surfx
Atomflo



Plasmatreat
RotaryJet

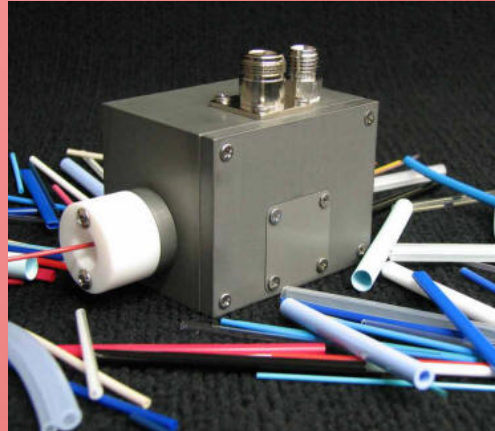


Iplas
Cyrannus

Continuous Profiles



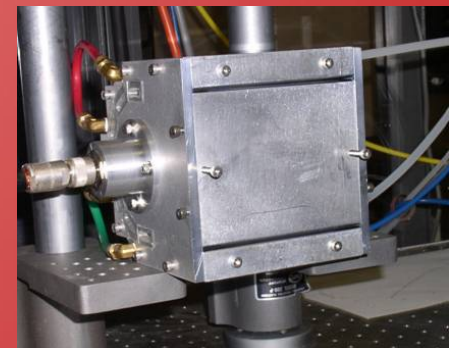
PlasmaTreat
Profile tunnel



Surfx
Atomflo 400T

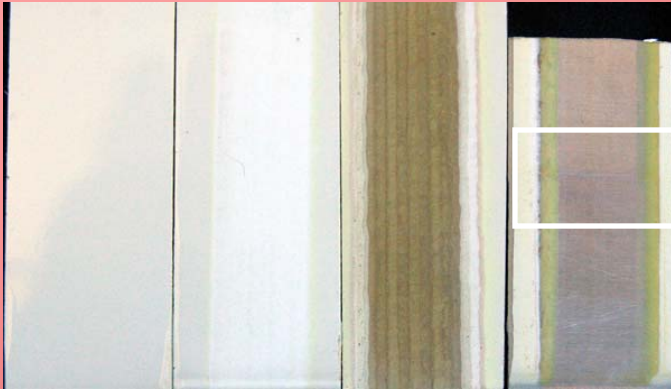


Tantec
CableTEC

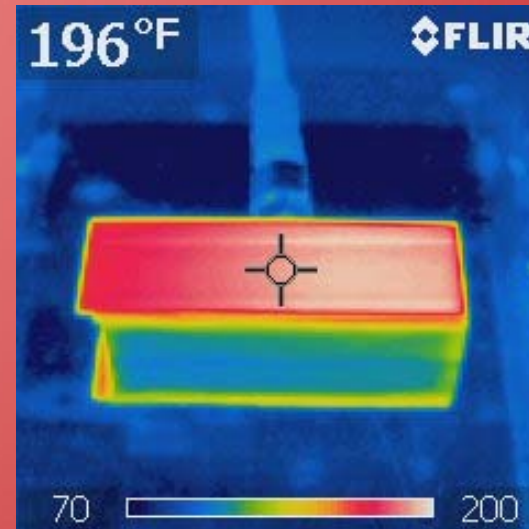
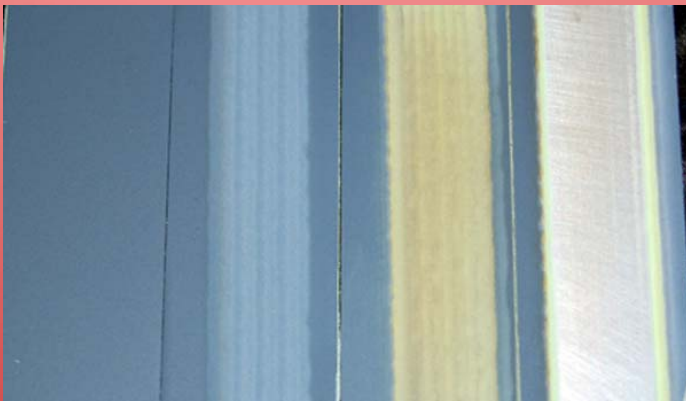


Apjet
Rollerjet

Plasma Paint Removal



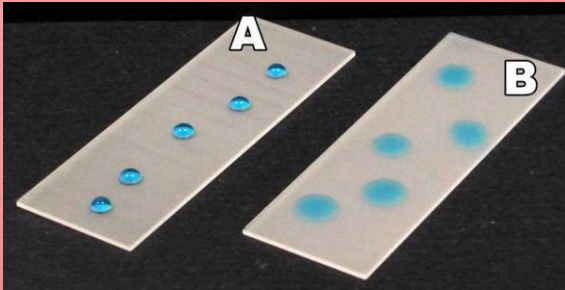
Enlarged View



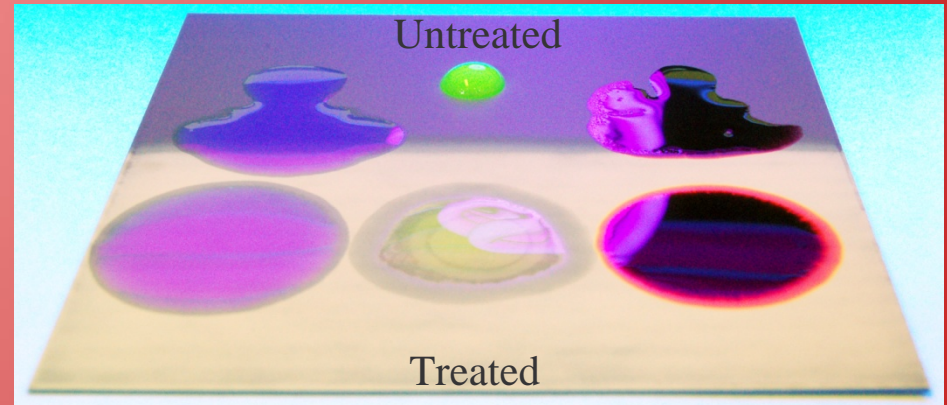
Infrared image
after treatment

Layered paint removal from 1"x 3" coupons
MIL 85285/23377 on 2024Al

Plasma Treatment Increases Surface Energy



Hydraulic fluid Water Mineral oil
MIL 83282



A: Hydrophobic surface before treatment
B: Hydrophilic surface after treatment

Dyne solutions and contact angles
can be used to measure surface
energy

Fluid drops with fluorescent dye on
MIL85285 polyurethane painted
aluminum illuminated with a black light

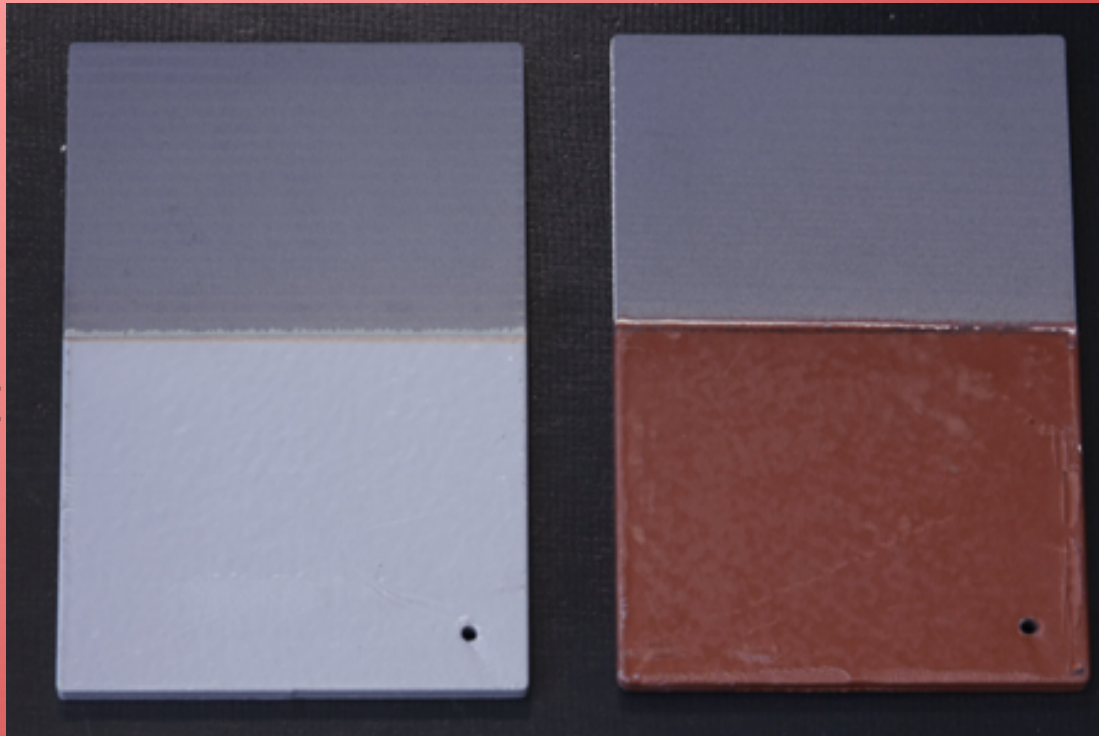
NAVSEA Paint

After
Plasma

After
Plasma

Before
MIL PRF 24635E
Haze Grey
MIL DTL 24443
Epoxy Primer

Before
MIL 24647
Anti-Fouling
MIL DTL 24443
Epoxy Primer



SSPC SP-10/NACE2 Mild Steel

Si Alkyd Ablative Paint/Steel



Panel subjected to
Seawater Immersion

Base metal after
atmospheric plasma

Plasma Sealant Removal from Fasteners

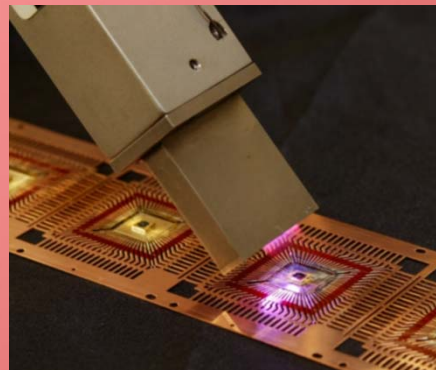
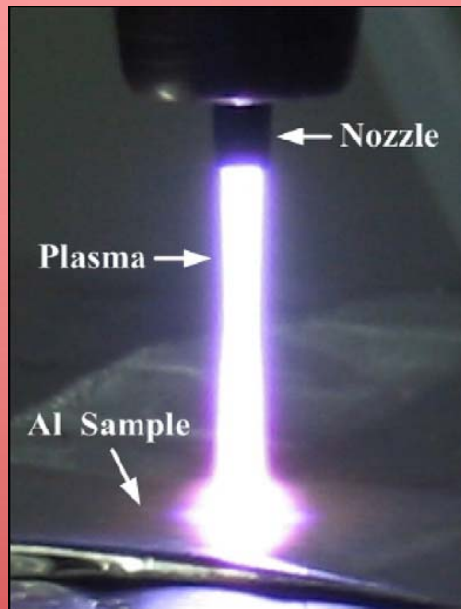
Before

After



MIL-PRF-81733 Polysulfide

Oxidation and Reduction



SurfX
Atomflo



AcXys



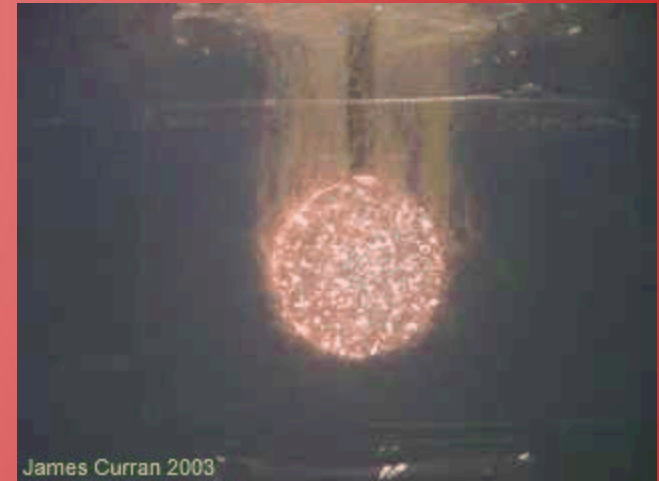
Surfx
H2 Plasma

D.H. Shin "μWave Plasma"
Surface & Coating and Technology 201 (2007)

Plasma Electrolytic Polishing and Oxidation

(Micro Arc Oxidation)

- Solid, Liquid, Gas, and Plasma
- Higher voltages than conventional anodizing: $200\text{ V} <$
- Acidic or alkaline aqueous solutions
oxide thickness $< 100\mu\text{m}$
- Crystalline oxides
Hard, tough: Al, Mg, Ti



Keronite.com



Summary

- Atmospheric Plasma is complex
- Numerous applications both for Oxidation and for Reduction
- Rapid Advancement in Applications
- Fundamental Understanding is Lacking

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Thank You



NCSU De-paint Video